Determinants of Ventricular Defibrillation in Adults

JOSEPH A. GASCHO, M.D., RICHARD S. CRAMPTON, M.D., MICHAEL L. CHERWEK, M.D., JAMES N. SIPES, M.D., FRANK P. HUNTER, B.E.E., AND WILLIAM M. O'BRIEN, M.D.

SUMMARY Conventional defibrillators which stored no more than 400 J and used damped sine wave pulses defibrillated 240 of 253 (95%) episodes of ventricular fibrillation (VF) in 94 prospectively assessed resuscitations in 88 adults. Shocks of 80–240 J (under 3 J/kg) delivered to the chest wall defibrillated more often than higher energy levels. Defibrillation rate did not correlate with weight. Defibrillation was determined by the diagnosis and setting in which VF occurred. Patients with acute myocardial infarction (AMI) and primary VF or with coronary disease and no AMI defibrillated more easily than patients with AMI and secondary VF or with no coronary disease. VF in a terminal patient (agonal VF) defibrillated less often than VF in other clinical situations. Age, weight, delivered energy, duration of pulse wave, and duration of VF had little, if any, influence on rate of defibrillation. These data fail to support the use of more expensive, high-output defibrillators sold by 11 of 14 American manufacturers.

ALTHOUGH ELECTRIC SHOCK has defibrillated human hearts since 1947, the threshold energy or current for human ventricular defibrillation is controversial. A retrospective analysis of 178 patients showed an apparent inverse relation between defibrillation rate and weight. These investigators also suggested that contemporary devices which store no more than 400 J can defibrillate only half the patients who weigh more than 80 kg. In contrast, prospective studies indicated no relation between weight and defibrillation rate. The recommended energy to defibrillate the ventricles ranges from 200–400 J.

If heavy patients do fail to defibrillate after shocks from devices now in clinical use for nearly 2 decades, then more powerful devices should be manufactured. However, if no relation exists between weight and outcome of countershock, the admonition to use the "megawatt" defibrillator may not only injure the heart, but also preclude successful resuscitation.

We prospectively evaluated 94 resuscitative events in 88 patients shocked for ventricular fibrillation (VF). We examined the relations among defibrillation, weight, delivered energy, pulse wave, duration of VF, clinical diagnosis, and setting in which VF occurred.

Methods

From September 1, 1975, resident physicians, nurses in the coronary unit and cardiac ambulance technicians, instructed to attempt ventricular defibrillation with 200 J or less, participated in 94 resuscitative events in 88 patients in VF. Ventricular tachycardia and flutter were specifically excluded. The stored energy of initial shocks was 200 J or less in 78 of 94 (83%), and for all shocks, stored energy was 200 J or less in 220 of 414 (53%). All but one of the shocks were delivered via conventional electrodes 8.0–8.8 cm in diameter, placed on the chest wall at the right upper sternal edge at the second interspace and over the cardiac apex at the left fifth interspace at the midclavicular and anterior axillary lines. During elective cardioversion of atrial fibrillation with electrodes placed in an anteroposterior orientation, one patient acquired VF and defibrillated with one shock. Electrode paste or saline-soaked gauze pads were usually placed between the electrodes and skin.

The clinical diagnosis, setting in which VF occurred, age and weight of each patient were noted. The patients were grouped into four categories: 1) acute myocardial infarction (AMI) and primary VF; 2) AMI and secondary VF; 3) coronary disease without AMI with either primary VF or secondary VF; and 4) all other patients. Myocardial infarction was diagnosed by typical serial, evolving Q, ST and T changes, elevation of cardiac enzymes, or fresh necrosis at necropsy. Coronary disease without infarction was diagnosed by a history of ischemic chest pain, normal cardiac enzymes, or absence of recent necrosis at necropsy. Primary and secondary VF were defined, respectively, as VF without or with left ventricular failure. The latter diagnosis was made by detection of a third sound gallop. VF which appeared secondarily in patients with terminal illness or after sudden collapse without basic life support was designated agonal VF. All other VF was defined as nonagonal.

The number of episodes of VF and the number of shocks for each episode and for all episodes of VF were recorded for each resuscitative event. Each resuscitative event included all episodes of VF that occurred within 2 hours of each other. If two episodes of VF occurred more than 6 hours apart in the same person, they constituted, for analytic purposes, separate events in separate patients. Thus, three patients entered the study twice and one four times for VF episodes 9, 12 and 15 hours and 1 and 5 weeks apart.
The outcome of each shock and of each resuscitative event was noted. A shock was considered successful if VF was converted to any other rhythm. The outcome of the resuscitative event was classified into four categories: 1) failure of the shock at the last attempt; 2) defibrillation by the last shock but death later in the resuscitative event; 3) discharge from hospital alive with resumption of active life.

Twenty-six standard devices (Physio-Control Series 70 and Lifepaks 33, 2 and 4; Hewlett-Packard 7802B and D and 780-02A; Cardiac Recorders IPCO-Pantridge 280; Zenith-Travenol Monopulse) delivered 414 DC shocks. Four hundred eleven of 414 shocks used damped sine waves 5 or 12 msec in duration. Three shocks used the 8-msec pulse of the Zenith-Travenol device. The stored energy was read from the meter or dial of the device. The energy delivered by discharging each device through a 50 Ω test load (Dempsey tester) was measured at least three times at each of five metered stored levels of energy of 50, 100, 200, 300 and 400 J. The recorded energy delivered in joules at the selected stored energy was considered the energy delivered to the patient. The stored and delivered energy and the delivered energy per unit weight were recorded for each shock.

Because the success or failure of the initial shock might influence selection of the energy level later in the resuscitative event, and because deteriorating metabolic conditions might deleteriously affect the outcome of the VF episode, the outcome of all shocks, the outcome of the first shock of each VF episode, and the outcome of the first shock of the resuscitative event were each noted. Success in terminating VF on the first shock and success regardless of the number of shocks required was tabulated. To remove the bias of energy level chosen after the outcome of the first shock, an analysis of variance was used to examine the first shock of the first VF episode in the 74 patients in whom the duration of VF was known.

All patients received standard basic and advanced cardiac life support. All with witnessed onset of VF received basic life support in less than 30 seconds if a shock failed.

Whenever possible the duration of VF before the first shock of the resuscitative event was noted. It could most often be determined accurately in monitored patients. The duration of VF in patients who collapsed outside the hospital was defined as time from collapse to first shock.

All data are presented as the mean ± SD. The statistical techniques used were Fisher's exact test (FET), chi-square test, analysis of variance and discriminant function (df).

Results

Ninety-four patients received 414 cross-chest DC shocks for 253 episodes of VF. Sixty-nine (73%) were men and 25 were women; mean age was 60.5 ± 15.6 years. They weighed from 40-225 kg (mean 72.7 ± 20.6 kg); 12 (13%) weighed more than 90 kg. Two hundred forty of 253 (95%) episodes of VF converted to another rhythm, 190 (75%) on the first shock (fig. 1). Eleven (12%) patients were defibrillated outside the hospital. All other resuscitative events began or ended in the following areas: coronary care unit — 32, general hospital — 25, emergency department — 14, other critical care units — 11, progressive coronary care unit — three, and cardiac catheterization laboratory — one. Events which began in one geographical area and ended in another were assigned to both areas if ventricular defibrillation was attempted in each area. Thus, there were 97 locations for the 94 resuscitative events.

Relation of Weight to Defibrillation

Figure 2 relates the frequency of defibrillation of the 253 episodes of VF to weight. The success of countershock did not decline as weight increased. Twelve patients weighed more than 90 kg. Forty-five
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Figure 2. Ventricular defibrillation rate vs weight. Weight did not determine rate of defibrillation.

of 46 (98%) episodes of VF defibrillated with 194 ± 76 delivered J or 1.8 ± .6 J/kg in these heavy people.

Relation of Delivered Energy to Defibrillation

The mean delivered defibrillating energy was 196 ± 85 J (2.7 ± 1.4 J/kg) for all 240 episodes defibrillated. The 190 episodes ended on the first shock defibrillated with only 180 ± 74 J (2.5 ± 1.2 J/kg). In 201 of the 253 episodes, defibrillation was attempted with shocks delivering 200 J or less. This energy level succeeded in 181 (90%) and in 160 (80%) with the first attempt.

Figure 3 relates the outcome of the shock to the delivered energy per kilogram. For all shocks (fig. 3A) there was a significant decline in defibrillation as delivered energy increased above 3 J/kg ($\chi^2 = 49$, df = 5, $p < 0.05$). Shocks which delivered under 2 J/kg were not significantly less effective than shocks which delivered 2–2.9 J/kg ($\chi^2 = 2.6$, df = 1, $p = 0.11$).

Figure 4 relates the outcome of the shock to the total delivered energy. For all shocks for all episodes of VF, three groups of energy levels at or below 240 J appeared equally effective (fig. 4A). In contrast, shocks delivering over 240 J failed more often ($\chi^2 = 163$, df = 3, $p < 0.0005$).

The lower success rate of shocks of higher energy might result from many unsuccessful shocks at full device output late in resuscitation in a minority of patients. To remove this possible bias, we examined the frequency of defibrillation by the first shock for each episode of VF and of the first shock of the first episode of VF for each patient, to delivered energy per unit weight (figs. 3B and C) and energy (figs. 4B and C). Although shocks that delivered 2–2.9 J/kg appeared more successful than either lower or higher energy levels, no significant trend was detected (figs. 3B and C). There was no apparent optimal energy level (figs. 4B and C).

Relation of Duration of VF to Defibrillation

The relation of duration of VF to defibrillation was examined in the 74 patients in whom the duration of VF before the first shock of the resuscitative event was known. The mean duration of VF was 175.6 ± 323 sec (range 2–1800 sec). The four episodes of VF which did not defibrillate lasted 153 ± 97 sec and the 70 defibrillated episodes lasted 176 ± 328 sec. Figure 5 relates defibrillation to duration of VF in three
Figure 4. Ventricular defibrillation rate vs total delivered energy. A) When total delivered energy exceeded 240 J in 414 shocks in 253 ventricular fibrillation (VF) episodes, defibrillation rate fell significantly. B) No optimal energy level appeared in first shocks of 253 VF episodes. C) In first shocks of 94 first VF episodes, no optimal energy level appeared.

Figure 5. Ventricular defibrillation rate vs duration of ventricular fibrillation (VF) before first shock of first episode. The duration of VF did not determine rate of defibrillation.

Figure 6. Outcome of resuscitative event: agonal vs non-agonal ventricular fibrillation (VF). The type of VF determined the outcome of the resuscitative event. None with agonal VF lived to return home.
Relation of Type of VF to Defibrillation

The setting in which VF occurred was related to defibrillation (fig. 6). Nineteen of the 94 (20%) patients had 55 episodes of agonal VF. None left the hospital alive. In contrast, 29 of 75 (39%) of patients with non-agonal VF returned home. Ten of the 19 patients (53%) with agonal VF did not defibrillate with the last shock. In contrast, only three of 75 patients (4%) with nonagonal VF failed to defibrillate with the last shock. Patients with nonagonal VF both defibrillated more frequently, and responded more frequently to the first shock (fig. 7). When first shocks delivered 200 J or less, 137 of 164 (84%) episodes of nonagonal VF defibrillated more frequently than did 24 of 37 (65%) agonal episodes ($p < 0.03$). There was no difference in rate of defibrillation between patients with agonal and nonagonal VF when duration of VF was 30 seconds or less. However, patients with agonal VF defibrillated less often at the first shock and also less often regardless of the number of shocks (fig. 8).

Relation of Diagnosis to Defibrillation

Table 1 relates defibrillation to diagnosis. Eighty-eight resuscitative events took place in 82 medical patients. Four patients had recently had a major operation: insertion of prosthetic cardiac valves in two, neurologic surgery in one and plastic surgery in one. Two patients had injured chests from automobile accidents.

Patients with AMI and primary VF and with coronary disease and no AMI usually defibrillated at the first shock and never failed to defibrillate. Three patients with AMI and secondary VF did not defibrillate. When attempted, under 200 J defibrillated 37 of 38 (97%) VF episodes with 33 (87%) defibrillated after one shock.

Patients without coronary disease defibrillated easily if VF was nonagonal. Nine of 12 such in-
individinals in agonal VF did not defibrillate. Shocks which delivered 200 J or less defibrillated 71 of 83 (86%) VF episodes, with 65 (78%) defibrillated after one shock.

Relation of Duration of Pulse Wave to Defibrillation

In 84 resuscitative events the 5-msec pulse was used, in 18 the 12-msec pulse and in one the 8-msec pulse. Thus, 103 pulse waves were used in the 94 resuscitative events. Both 5- and 12-msec pulses were used in eight resuscitative events and both 8- and 12-msec pulses in one. The defibrillation rates of the 5- and 12-msec pulses differed little. The 12-msec pulse defibrillated 52 of 54 (96%) VF episodes and the 5-msec pulse 188 of 198 (95%). In nonagonal VF, the 12-msec pulse defibrillated 43 of 43 (100%) VF episodes and the 5-msec pulse 154 of 157 (98%). In agonal VF, the 12-msec pulse defibrillated nine of 11 (82%) and the 5-msec 34 of 41 (83%) episodes. The 5-msec pulse seemed slightly superior to the 12-msec pulse in two subgroups. In the first shock of a first episode of VF, the 5-msec pulse defibrillated 77 of 92 (84%) and the 12-msec pulse five of 10 (50%) VF episodes ($x^2 = 4.1, p < 0.05$). In the first shock of all nonagonal VF episodes, the 5-msec pulse defibrillated 133 of 157 (85%) and the 12-msec pulse 29 of 43 (67%) VF episodes ($x^2 = 5.5, p < 0.05$). The 8-msec pulse failed to defibrillate in the single agonal VF episode in which it was used.

Analysis of Variance

The first shock delivered to each of 74 patients was examined when duration of VF was known. We considered only the first shock given to each patient instead of all shocks. Several possible biases were thus eliminated. The selection of energy level after the first shock might be biased by the result of the first shock. The failure to defibrillate after subsequent shocks of higher levels of energy in some patients might reflect metabolic deterioration or electrical injury during the resuscitative event rather than an inverse relation of energy to defibrillation rate. Age, weight, delivered energy in joules, length of pulse wave, duration of VF and type of VF were assessed for their influences on success or failure of DC shock. Only two variables distinguished successful from failed shocks per patient: type of VF and duration of pulse wave (table 2). Forty-four of 59 (75%) nonagonal patients defibrillated after their first shock compared with six of 15 (40%) patients with agonal VF. Forty-six of 65

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>n</th>
<th>Left hospital alive n (%)</th>
<th>Survived resuscitative event n (%)</th>
<th>Defibrillated; died during resuscitative event n (%)</th>
<th>Not defibrillated on last shock n (%)</th>
<th>Episodes of ventricular fibrillation</th>
<th>Defibrillation attempted with ≤ 200 J delivered energy n (%)</th>
<th>Successful n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMI, VF primary</td>
<td>14</td>
<td>7 (50)</td>
<td>12 (80)</td>
<td>2 (14)</td>
<td>0 (0)</td>
<td>43</td>
<td>39 (91)</td>
<td>38 (98)</td>
</tr>
<tr>
<td>AMI, VF secondary</td>
<td>18</td>
<td>4 (22)</td>
<td>9 (50)</td>
<td>6 (33)</td>
<td>3 (17)</td>
<td>63</td>
<td>41 (65)</td>
<td>54 (89)</td>
</tr>
<tr>
<td>Coronary disease without AMI</td>
<td>14</td>
<td>2 (14)</td>
<td>9 (64)</td>
<td>5 (36)</td>
<td>0 (0)</td>
<td>35</td>
<td>31 (89)</td>
<td>26 (96)</td>
</tr>
<tr>
<td>Other</td>
<td>48</td>
<td>16 (33)</td>
<td>20 (42)</td>
<td>8 (31)</td>
<td>10 (21)</td>
<td>112</td>
<td>79 (71)</td>
<td>83 (86)</td>
</tr>
<tr>
<td>Other with agonal VF</td>
<td>12</td>
<td>0 (0)</td>
<td>1 (8)</td>
<td>2 (17)</td>
<td>9 (75)</td>
<td>24</td>
<td>9 (38)</td>
<td>14 (70)</td>
</tr>
<tr>
<td>Other with nonagonal VF</td>
<td>36</td>
<td>16 (44)</td>
<td>19 (53)</td>
<td>18 (50)</td>
<td>1 (3)</td>
<td>88</td>
<td>70 (80)</td>
<td>69 (64)</td>
</tr>
</tbody>
</table>

Abbreviations: AMI = acute myocardial infarction; VF = ventricular fibrillation.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Defibrillated (mean, n = 50)</th>
<th>Failed to defibrillate (n = 24)</th>
<th>t value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type VF</td>
<td>1.880</td>
<td>1.625</td>
<td>3.002</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Agonal = 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonagonal = 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse wave (5 and 12 msec)</td>
<td>5.56</td>
<td>6.58</td>
<td>-2.459</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Duration VF (sec)</td>
<td>188.3</td>
<td>147.3</td>
<td>1.250</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>71.12</td>
<td>76.44</td>
<td>-1.069</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Energy (J)</td>
<td>149.36</td>
<td>153.13</td>
<td>-0.205</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Age (years)</td>
<td>59.4</td>
<td>60.0</td>
<td>-0.091</td>
<td>&gt;0.9</td>
</tr>
</tbody>
</table>

Degrees of freedom: between 6, within 67, total 73; F ratio 2.539; p <0.05.
(71%) pulse waves 5 msec long defibrillated, compared with four of nine (44%) pulse waves 12 msec long.

Patients Failing Defibrillation

Table 3 portrays clinical data of six individuals never defibrillated. Five had agonal VF. In three, VF appeared only after onset of electromechanical uncoupling or asystole.

Table 4 depicts the clinical data of seven patients who defibrillated early during the resuscitative effort, but who did not defibrillate during the last episode of VF. Five had agonal VF. In three, VF appeared only after resuscitation for electromechanical uncoupling or asystole. Three patients (cases 55, 83 and 93) received only one shock during the last episode of VF because the responsible physicians felt that repetitive defibrillation would neither prevent death nor restore satisfactory quality of life. Three patients with non-agonal VF did not defibrillate with the last attempted shock. Case 77, a 42-year-old man with disseminated neurofibromatosis and its cardiomyopathy who died 4 days after excision of brachial lesions, never defibrillated, despite 13 shocks (table 3). Case 72, a 72-year-old man recovering from acute renal tubular necrosis and pneumonitis from gram negative rods, had mild metabolic acidosis. After sudden onset of atrial fibrillation with ventricular rate 200 beats/min and hypotension, he received 0.375 mg of digoxin i.v. Cardiopulmonary arrest due to asystole occurred. With basic life support and pharmacologic intervention,20 the asystole converted to VF, and the first

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Age (years)</th>
<th>Diagnosis</th>
<th>Highest energy not defibrillating (J)</th>
<th>Highest not defibrillating (J/kg)</th>
<th>Shocks (n)</th>
<th>VF type</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>82</td>
<td>Septic shock</td>
<td>323</td>
<td>7.5</td>
<td>8</td>
<td>Agonal</td>
</tr>
<tr>
<td>56</td>
<td>43</td>
<td>Chronic lymphocytic leukemia, septic shock</td>
<td>236</td>
<td>4.2</td>
<td>6</td>
<td>Agonal*</td>
</tr>
<tr>
<td>59</td>
<td>65</td>
<td>Lymphoma, pneumonia</td>
<td>260</td>
<td>4.1</td>
<td>4</td>
<td>Agonal</td>
</tr>
<tr>
<td>60</td>
<td>63</td>
<td>Chronic obstructive pulmonary disease, acute renal failure</td>
<td>319</td>
<td>6.3</td>
<td>3</td>
<td>Agonal†</td>
</tr>
<tr>
<td>63</td>
<td>62</td>
<td>Subarachnoid hemorrhage</td>
<td>319</td>
<td>4.9</td>
<td>5</td>
<td>Agonal*</td>
</tr>
<tr>
<td>77</td>
<td>42</td>
<td>Neurofibromatosis, 4 days after operation</td>
<td>319</td>
<td>3.5</td>
<td>12</td>
<td>Nonagonal</td>
</tr>
</tbody>
</table>

Mean ± sd: 60 ± 14 296 ± 35 5.1 ± 1.4 6.3 ± 3.0

*VF preceded by electromechanical uncoupling.
†VF preceded by asystole.

Abbreviation: VF = ventricular fibrillation.

Table 4. Ventricular Defibrillation—Patients Defibrillated Early Who Failed to Defibrillate in the Last Episode of Ventricular Fibrillation (VF)

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Age (years)</th>
<th>Diagnosis</th>
<th>Lowest defibrillating earlier (J)</th>
<th>Highest not defibrillating (J)</th>
<th>Final episode failed shocks</th>
<th>VF Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>70</td>
<td>Stroke, acute myocardial infarction, secondary VF</td>
<td>152</td>
<td>3.1</td>
<td>332</td>
<td>6.9</td>
</tr>
<tr>
<td>36</td>
<td>54</td>
<td>Myasthenia gravis, necrotizing pneumonia</td>
<td>225</td>
<td>3.8</td>
<td>255</td>
<td>3.8</td>
</tr>
<tr>
<td>55</td>
<td>50</td>
<td>After prosthetic mitral and aortic valve implant, pacemaker</td>
<td>167</td>
<td>2.8</td>
<td>342</td>
<td>5.7</td>
</tr>
<tr>
<td>72</td>
<td>72</td>
<td>Renal failure, acidemia, digoxin treatment</td>
<td>155</td>
<td>2.6</td>
<td>319</td>
<td>5.4</td>
</tr>
<tr>
<td>83</td>
<td>62</td>
<td>Cardiogenic shock, acute myocardial infarction</td>
<td>185</td>
<td>2.4</td>
<td>95</td>
<td>1.2</td>
</tr>
<tr>
<td>84</td>
<td>61</td>
<td>Acute myocardial infarction, secondary VF</td>
<td>95</td>
<td>1.5</td>
<td>372</td>
<td>5.9</td>
</tr>
<tr>
<td>93</td>
<td>91</td>
<td>Pneumonia, saddle embolus</td>
<td>155</td>
<td>2.3</td>
<td>319</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Mean ± sd: 66 ± 13

162 ± 36 2.6 ± 0.7 291 ± 86 4.8 ± 1.7 4.7 ± 4.0

*VF preceded by electromechanical uncoupling.
†VF preceded by asystole.
defibrillated. When VF recurred, 11 subsequent shocks, each delivering 319 J, failed to defibrillate (table 4). Case 83, a 62-year-old man with AMI and left ventricular failure, suddenly developed complete atrioventricular block with subsequent electromechanical uncoupling. After basic life support and pharmacologic intervention,20 VF appeared, and each of four VF episodes terminated with a single 185-J shock. A fifth VF episode did not respond to a single shock, and resuscitation was abandoned (table 4).

Discussion

We found no relation of weight of the patient to defibrillation rate (fig. 2). Others have also failed to correlate weight and defibrillation rate.4-8 In four prospective studies,6-8 defibrillation rate did not decrease with increase of weight. One retrospective investigation revealed no difference in energy delivered to defibrillated patients and those not defibrillated. These reports6-8 and our results differ from a retrospective study which showed an apparent decrease in defibrillation as weight increased.4,4 The reason for this difference is unclear. In the retrospective analysis suggesting that defibrillation rate decreased with increase of weight, 40% of the attempted defibrillations in 111 patients occurred immediately after cardiac surgery.5,22 The diagnoses in the remaining 60% are unknown. None of the patients in the largest prospectively assessed group were defibrillated immediately after cardiac surgery.5,6,8 Only four patients in our study were postoperative, two cardiac and two noncardiac. It seems possible that surgical complications, metabolic derangement, or acute cardiac dysfunction might render defibrillation in the postoperative state difficult or impossible.

Our data indicated no relation in the energy spectrum we used between defibrillation and delivered energy, whether expressed as joules or joules per kilogram. A trend appeared for a higher success rate with 2.0-2.9 J/kg than with a higher or lower energy levels per unit weight (fig. 3). Moreover, when all shocks were analyzed, defibrillation rate decreased as energy level rose above 3.0 J/kg (fig. 3A). This may have reflected multiple high-energy shocks given to a minority of patients failing earlier shocks. Nevertheless, injurious effects of higher levels of electrical energy cannot be excluded as a reason for our failure to defibrillate these patients.

In most of our patients’ episodes of VF (201 of 253, 80%), defibrillation was attempted with 200 J or less. One hundred eighty-one (90%) defibrillated at that low energy (table 1), and 160 of 201 (80%) defibrillated at the first shock. A higher percentage might have defibrillated at this energy level had the resuscitators not increased energy after only one failed shock at 200 J or less. In only four of 20 episodes failing defibrillation at that energy was a second shock delivering 200 J or less attempted. Others have reported high success rates with energy of 74-165 J.6 Several investigators have acknowledged that “low-energy shocks” may defibrillate,22 but only when “multiple shocks with less energy”24 are used in contrast to “a single shock of slightly higher energy.”22 Our data support none of these contentions.

The lack of relation among defibrillation, weight, energy, or energy per unit weight was not noted by other investigators.25 Ventricular defibrillation thresholds were determined for many animal species from the rabbit to the horse by lowering energy or current in 10% decrements from the level of an initially successful shock until the shock failed.26 A close relation between weight and energy (E = 0.73 wt1.52; E = energy in joules, wt = animal weight in kilograms), and an even closer relation between weight and current (I = 1.87 wt0.88; I = current in amperes, wt = animal weight in kilograms), was claimed. If this equation were applied to man, one would predict that devices storing only 400 J and delivering only 300-340 J could not defibrillate heavy patients. Our data, which show high success rates even with shocks delivering 200 J or less, suggest that these animal data do not apply to defibrillation of man. In fact, the 100-kg calf in VF needed four to five times more energy to defibrillate, 862 J or 8.6 J/kg,26 than did our patients in this weight range. Pigs57 and ponies24 required even more energy, 958 J or 8.7 J/kg, and 1602 J or 10.6 J/kg, respectively, to defibrillate. Since animals whose weight was identical to our heavier patients (91-225 kg) needed four to eight times as much energy to defibrillate, the extrapolation of energy levels to defibrillate calves, pigs and ponies to humans seems unwarranted, if not dangerous.

The limitations of a similar formula (E = 1.88 wt1.16; E = energy in J, wt = patient weight in kg) for energy requirements for human ventricular defibrillation1 have been delineated.2 The data base for the human equation consisted of only 13 human defibrillations (seven adult and six pediatric). In 10, defibrillation failed at one energy level but occurred at a higher energy level. This higher level was deemed the defibrillation threshold energy.2 In three infants also included in the derivation of this formula, the initial shock was apparently successful.

The human formula is questionable for several reasons. First, it is derived from retrospective data of only 10 patients. It is truly incorrect to include the three infants, since no failing shocks of lower energy defined threshold. Second, it is uncertain that the energy level determined was truly the lowest capable of defibrillating. There may have been large increases in energy between the initial failing and final successful shock without investigation of intermediate energy levels. Any intermediate value might have succeeded. Third, frequently a shock of the same energy as the initial failing shock may defibrillate, perhaps because the first shock lowers impedance, allowing more current to flow with the second shock.5,28,29

Our data do not support the assertion that only half of patients weighing more than 82 kg can be defibrillated with conventional defibrillating devices storing no more than 400 J;2 nor do they support the
suggestion that more powerful defibrillators be developed.\textsuperscript{3, 18}

It is generally accepted that there is an inverse relation between the duration of VF and rate of defibrillation. Our data do not suggest that duration of VF is an important determinant of defibrillation (fig. 8). In fact, several patients in VF for 10-30 minutes outside and inside the hospital defibrillated, perhaps reflecting our community’s aggressive basic life support.

Analysis of variance indicated that the 5-msec pulse on the first shock was a determinant of ventricular defibrillation. However, the number of 12-msec shocks in this category was small. The 5- and 12-msec pulses were equally effective in most of our other larger samples. In those subgroups where the 5-msec pulse seemed superior at the first shock, no difference in defibrillation rate was seen for all shocks, regardless of the number. Moreover, the 12-msec pulse has been very effective in first shocks of a large number of patients with VF from an acute coronary event.\textsuperscript{5, 6, 8}

We confirmed\textsuperscript{6, 8} that patients with AMI and primary VF or with coronary artery disease without AMI defibrillated easily and at low levels of energy. Moreover, we demonstrated that patients with non-agonal VF without coronary disease also defibrillated easily. On the other hand, patients with secondary VF and AMI, and patients with agonal VF without coronary disease defibrillated with more difficulty (table 1). The diagnosis and type of VF thus predict defibrillation better than weight or energy. Although these parameters have not been formally assessed in the past, patients with VF secondary to metabolic abnormalities, terminal malignancy or AMI complicated by cardiogenic shock or heart failure would be more difficult to defibrillate than patients with primary VF or no AMI.

Other reports indicate that the diagnosis is an important determinant.\textsuperscript{3-5, 8} A high success rate has been documented in primary VF due to acute coronary events.\textsuperscript{5, 6, 8} In 40% of patients in the large retrospective study,\textsuperscript{2, 4} defibrillation was attempted immediately after cardiac surgery. The lower rate of defibrillation noted in this study may relate to surgical complications, a long operation, anesthetic agents, other drugs, metabolic derangement, or other acute postoperative problems.

A more powerful defibrillator might defibrillate a few more patients with agonal VF, but it is unlikely that defibrillation of such patients would significantly prolong life, let alone maintain or improve its quality. Of the 19 patients with agonal VF, nine defibrillated at last shock. Only two survived the resuscitative event, and then died later in the hospitalization (fig. 6).

The heterogeneous VF population, the location of such patients at onset of VF outside hospital, in a coronary care or other critical care unit, or in the general hospital, the skill of the resuscitator in performing basic life support, in placing intravenous lines, in administering medications, and in properly placing defibrillator electrodes, and the use of electrode paste before attempting defibrillation, are all variables that make analysis of the determinants of ventricular defibrillation in man difficult. For instance, the decreased defibrillation rate in the retrospective analysis of some heavy patients may be attributed to greater difficulty in rendering basic life support or inserting intravenous lines.

The toxic effects of electric shocks are not fully known. Several patients received as many as 140 shocks of 180-220 J without apparent cardiac damage.\textsuperscript{20, 31} Although some workers failed to detect serious cardiac damage after experimental shocks in the dog,\textsuperscript{22} it nevertheless seems likely that high energy injures the heart.\textsuperscript{19, 33-36} In an animal model, ventricular arrhythmias occur more frequently as electrical energy increases.\textsuperscript{37} Although little morphologic damage was detected when dogs were shocked with current or energy similar to humans receiving 400 J,\textsuperscript{38} a radionuclide technique distinguished injury of the canine heart from a single 400-J shock from the apparently harmless 200-J shock.\textsuperscript{34} Studies using the rabbit heart\textsuperscript{38} and cultured cardiac cells from the chick embryo\textsuperscript{35} indicate that serious damage can occur at energy levels comparable to full device output of defibrillators storing no more than 400 J.

Our data confirm other reports\textsuperscript{5-8} and indicate that contemporary defibrillators storing no more than 400 J defibrillate 95% of all VF episodes and 99% of episodes of VF occurring in viable patients. Since high energy may damage the heart, there is no evidence to support manufacture and distribution of more powerful defibrillators; yet 11 of 14 American manufacturers now sell higher-output devices. It seems more logical to produce lighter, more portable and less expensive devices which deliver only 200 J for use in certain locations\textsuperscript{6} such as police, fire and rescue vehicles, office buildings, factories, large apartment blocks, large transportation terminals and carriers, stadiums, auditoriums, and especially homes of high-risk coronary patients.\textsuperscript{39}

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